The Miph of Consciousness

The Mathematics, Informatics, and Physics of Consciousness and its Place in Nature

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Toward a Science of Consciousness
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Introduction

- Formal logic
- Computation
- Set theory
- Possible worlds
- Quantum theory
- Consciousness
- Open questions
- Conclusion
What is consciousness?

- Is a state of
  - Phenomenal awareness of qualia
  - Being inside a universal reality
  - Being in a landscape of things

- Is a process of
  - Becoming aware of changing qualia
  - Experiencing new states of awareness
  - Sensing the ebb and flow of things

- Is essentially
  - Extended over a space of things
  - Rooted in a history of changes
  - Part of an ongoing logical process

Color qualia
Flow logic

- Fundamentally
  - We are immersed in eternity
  - We change in time

- Time is the dimension of
  - Growth
  - Change
  - History

  Fountainhead of possibility

Crucible of transformation

Accumulation of facts
A creation myth

- At time zero, all was calm

- In the Planck instant before the big bang, the physical universe had perfect symmetry

- The first symmetry to break open the primal egg was the complementarity of $0/1$ and $1/0$

- Bit states 0 and 1 started out equal and opposite

- The first moment of time broke the symmetry
As time advanced,
- Successive symmetries were broken
- From 11 compact dimensions 4 expanded
- The universe cooled and matter condensed
- Atoms aggregated in a sea of photons
- Symmetries broke randomly and entropy increased
- Phase changes created concentrations of order
- Ordered states became more complex
- DNA life evolved on Planet Earth
In the last few million years BP,
- Biological organisms such as human beings evolved subjective consciousness
- Consciousness grew to recognize increasingly complex objective domains

Knowledge and reality

Epistemic subject
Realm of knowledge

Ontic domain
Realm of reality
Some facts:

- Knowledge is generated by conscious human beings
- Human consciousness is generated by brain activity
- Conscious states are correlated with brain states
Brains are neuronets

- The human cerebral cortex contains \( \sim 10^{10} \) neurons
  - On average, a neuron connects with \( \sim 10^4 \) other neurons
  - The neurons are connected in layers to form sheets

- Neurons receive and emit electrical signals
  - They receive signals along **dendrites**
  - The dendrites terminate in **synapses**
  - A neuron emits signals along its **axon**
    - The signals are called action potentials
    - They are \( \sim 100 \) mV spikes that last \( \sim 1 \) ms
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- Introduction
- **Formal logic**
  - Computation
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The contents of consciousness are knowledge states
- Epistemology is the theory of knowledge
- Ontology is the theory of what exists

Knowledge states are propositional
- True propositions state what is the case
- False propositions state what is not

Propositions
- Bivalent
  - Truths
  - Falsehoods
  - P or not P
Bivalent propositions form classical logic
- True propositions $P$ have truth value 1: $v(P) = 1$
- False propositions $P$ have truth value 0: $v(P) = 0$
- Valid inference from $P$ to $Q$ preserves truth: $v(P) \leq v(Q)$

<table>
<thead>
<tr>
<th>TRUTH TABLE</th>
<th>Not $P$</th>
<th>$P$ and $Q$</th>
<th>$P$ or $Q$</th>
<th>If $P$ then $Q$</th>
<th>$P$ iff $Q$</th>
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<td>$P \land Q$</td>
<td>$P \lor Q$</td>
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Objects and concepts

Propositions have inner structure

- \( P = f(a) \)
  - Syntax
    - \( f = \) predicate
    - \( a = \) name
  - Semantics
    - \( f = \) concept or class
    - \( a = \) object or element
  - \( P \) states that
    - Object \( a \) falls under concept \( f \)
    - Element \( a \) is a member of class \( f \)

- \( P = f(a_1, \ldots, a_n) \)
  - \( P \) states that \( a_1, \ldots, a_n \) fall under n-ary relation \( f \)
First order logic

- General propositions use quantifiers and variables
  - For all objects $x$, $f(x)$
    $$\forall x f(x)$$
  - For some objects $x$, $f(x)$
    $$\exists x f(x)$$
  - Unquantified, $f(x)$ is an open sentence and $x$ is free
  - In classical first order logic,
    - For all $x$, $f(x)$ iff there is no $y$ such that not $f(y)$
      $$\forall x f(x) \iff \neg (\exists y) \neg f(y)$$
Valid inference

- Propositional inference
  - *Modus ponens*
    - $P, P \rightarrow Q \Rightarrow Q$
- Quantifier inference
  - For free variable $u$, $f(u) \Rightarrow (\forall x)f(x)$
  - $(\forall x)f(x) \Rightarrow f(z)$ for any $z$
  - For any $z$, $f(z) \Rightarrow (\exists x)f(x)$
  - $(\exists x)f(x) \Rightarrow f(c)$ for new constant $c$
- Different axioms and rules give different systems
  - Nonclassical systems often deny bivalence
- Implication
  - $A, ... \Rightarrow C$ is valid
    - iff conclusion $C$ is true whenever all the premises $A, ...$ are true
- Consistency
  - First order theory $T$ is consistent
    - iff, for all sentences $s$ of $T$, not both $T \Rightarrow s$ and $T \Rightarrow \lnot s$
A first order theory $T$
- Is a set of sentences $s$ in a first order language $L$ with a distinguished set of axioms and theorems
- Theory $T$ implies $L$-sentence $s$: $T \models s$

A model $M$
- For a first order theory $T$ is a set $\langle O, R \rangle$ where
  - $O$ is a set of objects denoted by terms in $T$
  - $R$ is a set of relations between objects in $O$
such that, when $L$ is interpreted in $O$ and $R$, the axioms and theorems of $T$ are true
- Model $M$ satisfies $L$-sentence $s$: $M \models s$

Completeness: for all $s$, $T \models s$ iff $M \models s$
Logic and consciousness

- L can be any symbolic interaction medium used by a conscious subject
  - L can be neurally hardwired, acted, spoken, written, embodied in tokens, coded as bits, ...

- M can model any world that embeds the subject
  - M can be the world denoted by an actual or potential conscious state of the L-using subject
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The realm of mathematical forms is
- Eternal, outside time
- Perfect and incorruptible
- Invisible to the vulgar senses

Numbers are eternalized abstractions of
- Arbitrary physical things
- The pure intuition of time

Number theory is a prototype for
- Any first order theory
- Any computable theory
- Any algorithmic process
- Any virtual reality

- Plato
- Kant
- Gödel
- Turing
- Chaitin
- Deutsch
Informal arithmetic

- Arithmetic is the theory of the natural numbers

Onward to the limit $\omega$ of the natural numbers

$\mathbb{N} = \{0, 1, 2, 3, \ldots\}$

$\mathbb{N}$ = the infinite set of natural numbers

$S(n) = \text{the successor of } n$

Basic operations
Addition $+$
Multiplication $*$
The axioms of formal arithmetic **FA**

For all $x, y, z \in \mathbb{N}$,

- $x = y \rightarrow (x = z \rightarrow y = z)$
- $x = y \rightarrow S(x) = S(y)$
- $0 \neq S(x)$
- $S(x) = S(y) \rightarrow x = y$
- $x + 0 = x$
- $x + S(y) = S(x + y)$
- $x \times 0 = 0$
- $x \times S(y) = (x \times y) + x$

For any **FA** predicate $A(\ )$,

- If $A(0)$ and $(\forall x)(A(x) \rightarrow A(S(x)))$ then $(\forall x)A(x)$
Theory and metatheory

- A theory is an epistemic construct $T$
  - $T$ is a set of interpreted propositions
  - The propositions define a knowledge state
- A theory refers to an ontic domain $M$
  - $T$ is interpreted in natural model $M$
  - $M$ satisfies the axioms and theorems of $T$
- A theory has a syntactic structure $S$
  - $S$ is made of uninterpreted formal symbols
- A metatheory of $T$ has the model $S$
  - Every theory $T$ has a metatheory $MT$
  - $T$, $MT$, $MMT$, ... can share the same $S$
A metatheoretic paradox

Let theory FA have metatheory MA

- Code the structure S of FA into the model N of FA
  - Define numbers for names, predicates, variables, constants
  - Define arithmetic operations to generate numbers for sentences, inferences, proofs, axioms, theorems
- Call the number n that codes an S-item s of FA the Gödel number G(s) of s: \( n = G(s) \)
- Define the open FA/MA sentence \( g \):
  - For all s, G(s) is not the Gödel number of a proof in FA of x
- An instance of \( g \) is FA/MA sentence \( g^* \):
  - For all s, G(s) is not the Gödel number of a proof in FA of g
  - \( g^* \) says \( g \) has no proof in FA, so \( g^* \) should be true in MA

- If FA is consistent, \( g^* \) is true but not provable in FA
Turing machines are idealized computers

Infinite tape
Read/write head
Binary symbols

Machine state

Machine table

<table>
<thead>
<tr>
<th>Machine state</th>
<th>Read symbol</th>
<th>Write symbol</th>
<th>Move head</th>
<th>Next state</th>
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</thead>
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<tr>
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<td>1</td>
<td>1</td>
<td>R</td>
<td>z</td>
</tr>
<tr>
<td>x</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>y</td>
</tr>
<tr>
<td>y</td>
<td>1</td>
<td>1</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>y</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R: right
L: left
H: halt

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Computable strings

1. Input: binary string on tape
2. Universal Turing machine \( U \) starts
3. \( U \) halts (maybe!)
4. Output: binary string on tape

Machine has halted

This is the output

- Computable strings are \( U \) output from given input strings
- Turing built on Gödel’s theorem for FA to prove:
  - **The halting problem**
    - It is not decidable for which input strings \( U \) halts
Are brains computers?

- Computers
  - Have digitized input and output
  - Have a finite number of inner states
  - Operate according to fixed rules

- Human brains
  - Have approximately digitized input and output (via sensory and motor nerves)
  - Have a vast but probably finite number of inner states (if similar states are equivalent)
  - Operate according to rules that are presumably fixed (but are complex and not well understood)
Brains may not be computers

- Truth outruns provability in arithmetic
  - Not all truths in FA can be proved in FA – Gödel
- FA theorems are computable strings
  - The set of computable strings is not computable – Turing
- Not all truths are computable
  - So brains are not computers – Penrose

Says Penrose ≠
Artificial neuronets (ANNs) reflect the gross architecture of natural cerebral neuronets.

An artificial neuron:
- Input $x_1$
- Weight $w_1$
- Input $x_2$
- Weight $w_2$
- Input $x_3$
- Weight $w_3$

Output:
$f(w_1x_1 + w_2x_2 + w_3x_3)$

An ANN:
Neuronets can be computers

- ANNs can compute any computable function
  - But how can they program themselves?
- ANNs with backpropagation can learn
  - Backpropagation is output fed back to reset weights
  - ANNs with backpropagation can use training input to reduce errors on pattern recognition tasks
- ANNs can emulate many brain functions
  - But how well can ANNs emulate brains?
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From numbers to sets

- Number theory is pure logic – Kant
- Numbers are sets of sets
- How to see numbers as sets:
  - Number $n$ is the set of all sets that can be mapped 1-1 onto $n$ – Frege
    - Problem: these sets are too big
  - Number 0 is the empty set $\{\}$
    Number $n + 1$ is the singleton of $n$, $\{n\}$ – Zermelo
    - Problem: these sets are too small
  - Number 0 is the empty set $\{\}$
    Number $n$ is the set of all $m$ for $m < n$ – von Neumann
    ✨ Bingo! These sets are just right
Elements and classes

- Sets are elements and/or classes
  - Elements a, b, c are members of class C: a, b, c ∈ C and C = {a, b, c, ...}

- In pure set theory, all elements are sets
  - The null set { } = ∅ and ∅ ∈ {∅} ∈ {∅, {∅}} ∈ ...

- Usually, classes are sets, but
  - Russell’s paradox
    The class of all sets that are not members of themselves, R = {x | x ∉ x},
    is a member of R iff it is not a member of itself:
    R ∈ R ↔ R ∉ R
  - So the universe V of all sets is a class but not a set
Power sets

The power set of $x$ is the set of all subsets of $x$

- If $x$ has $n$ members, $P(x)$ has $2^n$ members

$x = \{1,2,3,4,5\} \Rightarrow P(x) = \{\{\}, \{1\}, \{2\}, \{3\}, \{4\}, \{5\}, \{1,2\}, \{1,3\},\{1,4\}, \{1,5\}, \{2,3\}, \{2,4\}, \{2,5\}, \{3,4\}, \{3,5\}, \{4,5\}, \{1,2,3\}, \{1,2,4\},\{1,2,5\}, \{1,3,4\}, \{1,3,5\}, \{1,4,5\}, \{2,3,4\}, \{2,3,5\}, \{2,4,5\}, \{3,4,5\},\{1,2,3,4\}, \{1,2,3,5\}, \{1,2,4,5\}, \{1,3,4,5\}, \{2,3,4,5\}, \{1,2,3,4,5\}\}$

$P(N)$ cannot be mapped 1-1 onto $N$

- $N$ is a countably infinite set with cardinality $\aleph_0$
- $P(N)$ is uncountably infinite with cardinality $\aleph_1$
- Continuum hypothesis: $P(N)$ has cardinality $\aleph_1$
Zermelo-Fraenkel set theory

**ZF axioms**

For all \(x, y \in V\),

- **Extensionality**: \(x = y \iff (\forall z)(z \in x \iff z \in y)\)
- **Regularity**: \(x \neq \emptyset \rightarrow (\exists z)(z \in x \land z \cap x = \emptyset)\)
- **Pairs**: \(\{x, y\} \in V\)
- **Union**: If \(U(x) = \{u \mid (\exists v)(u \in v \land v \in x)\}\) then \(U(x) \in V\)
- **Power set**: If \(P(x) = \{u \mid u \subseteq x\}\) then \(P(x) \in V\)
- **Null set**: \(\emptyset \in V\)
- **Infinity**: If \(\omega = \{u \mid \emptyset \in u \land (\forall v)(v \in u \rightarrow v \cup \{v\} \in u)\}\) then \(\omega \in V\)
- **Replacement schema**: For any ZF function \(f\) from \(D\) to \(C\), \(D \in V \rightarrow C \in V\)
Every set has a rank

- Every ZF set \( x \) has an ordinal rank \( R(x) \)
  - The von Neumann definition of ordinal numbers \( \alpha \)
    \[
    0 = \emptyset = \{ \} \\
    \alpha = \{ \beta \mid \beta < \alpha \}
    \]
    (each ordinal is the set of all smaller ordinals)
  - The von Neumann transfinite V-set function \( V_\alpha \)
    \[
    V_0 = 0 \\
    V_\alpha = \mathcal{P}(V_{\alpha - 1}) \text{ for successor ordinals } \alpha
    \]
    (each successor V-set is the power set of its predecessor)
    \[
    V_\lambda = \bigcup \{ V_\alpha \mid \alpha < \lambda \} \text{ for limit ordinals } \lambda
    \]
    (each limit V-set is the union of all previous V-sets)
  - \( R(x) = \) the least ordinal \( \alpha \) such that \( x \subseteq V_\alpha \)
The universe of sets

- The cumulative hierarchy of pure well-founded sets

Diagram:

- Absolute infinity
- Ordinal rank
- Transfinite sets
- Hereditarily finite sets

\[ \emptyset = V_0 \]
First order theories have ranked models in $V$

- $C_1 = \{x \mid f_1(x)\} = \{a_1, a_2, a_3\}$
- $C_2 = \{x \mid f_2(x)\} = \{a_2\}$
Epistemology and ontology form a dialectic in V

The classes of each rank help define the elements of the next rank
A knowledge state is satisfied in a world
- A knowledge state is a set of true propositions
- A knowledge state is closed under logical inference
- True propositions state either tautologies or facts
- A world of knowledge is a totality of facts

New facts are informative
Worlds as universal sets

- Universal sets can represent worlds
  - Let set $V_\alpha$ be the natural model for set theory $T_\alpha$
  - If knowledge state $K_\alpha$ is logically isomorphic to $T_\alpha$, then $V_\alpha$ is a formal model for $K_\alpha$
  - If world $W_\alpha$ satisfies knowledge state $K_\alpha$, then $V_\alpha$ formally represents $W_\alpha$
Introduction
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Quantum theory
Consciousness
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Worlds as realities

- Worlds
  - Reflect states of
    - Information
      - Made of bits
        - = logical atoms
    - Knowledge
      - Made of facts
        - = cognitive atoms
    - Consciousness
      - Made of qualia
        - = sensory atoms
  - Closure
    - Made round
Worlds as closed loops

- Closure
  - In set theory, looping $V$ to 0 effects closure
    - But the loop is a paradox
  - For a **world** $W$ represented as a $V$-set,
    - Its universe $V$ is not an element, but $V$ can be nonuniversal **outside** $W$
    - Its urelement 0 has no members, but 0 can be nonempty **outside** $W$
  - Closure makes $W$ a totality
Virtual realities

- A world embeds a subject
  - The world is reality for the embedded subject

- A world may be actual or possible
  - An actual world is an existing state of
    - Information (bits)
    - Knowledge (facts)
    - Consciousness (qualia)
  - A possible world is a **virtual reality**
    - The VR is defined by computable rules from atomic bits to resemble the actual world relative to which it is possible
Possible worlds

- Worlds can be actual and/or possible
  - The actual world $G$ is the world as it is now
    - $G$ may be a state of knowledge or consciousness
  - Possible worlds $W$ are worlds as they may be
    - Worlds $W$ may be possible futures relative to $G$
  - An accessibility relation $R$ links pairs of worlds
Modal logic is the logic of possible worlds

There are two main modal operators

**Necessarily P**
- □P is true in G iff, for all worlds W such that W is R-accessible from G, P is true in W

**Possibly P**
- ◇P is true in G iff, for some world W such that W is R-accessible from G, P is true in W
Possible world semantics

Possible worlds form model structures
- A model structure $A = \langle G, K, R \rangle$ contains
  - Actual world $G$
  - Set $K$ of possible worlds $W$ (including $G$)
  - Relation $R(W, G)$ saying world $W$ is accessible from $G$

Satisfaction
- Truth conditions for sentences $s$ of modal language $L$ are defined relative to all $R$-accessible worlds $W$ in $K$
- If language $L$ defines modal theory $T$,
  a suitable model structure $A$ satisfies $T$: $A \models T$

Completeness
- For suitable modal theories $T$ and all sentences $s$ of $L$,
  $T \models s$ iff $A \models s$
Epistemic and ontic modalities

- Axioms for modal logic define
  - Necessarily P: □ P
  - Possibly P: ◊ P

- Different axioms are true in model structures A with different relations R

- In a modal theory, modalities may be
  - Epistemic / psychological
    - □ P if P is implied by what is known / believed
    - ◊ P if P does not contradict what is known / believed
  - Ontic / physical
    - □ P if the probability of P = 1
    - ◊ P if the probability of P > 0
Probabilities

- Probabilities are numerical weights attached to possible worlds such that
  - The probability of world \( W \), relative to world \( G \) in a model structure \( A \), is a real number \( p(W) \) between 0 and 1
  - The combined probability of two or more distinct worlds is the sum of their separate probabilities
  - Each world \( W \) such that \( R(W, G) \) is possible from \( G \)
    - Each \( p(W) > 0 \)
  - The worlds \( W \) such that \( R(W, G) \) cover all cases
    - \( \sum p(W) = 1 \)
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Quantum theory

- In classical physics, the world is eternal
  - Reality evolves rigidly along a fixed timeline
  - Exact laws determine the past and future
  - Statistical approximations generate probabilities
    - Classical probabilities are **epistemic**

- In quantum physics, the world is changing
  - Reality comes into focus along a growing timeline
  - The past is fixed but the future is fuzzy
  - The probability of possible futures is intrinsic
    - Quantum probabilities are **ontic**

- We live in a quantum world
  - Classical physics is out of date

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A world is a state of a physical system
- An actual world $G$ is a **real** state of the system
  - The complexity of $G$ reflects the theory $T$ defining it
- A possible world $W$ is a **virtual** state of the system
  - The complexity of $W$ is related to that of $G$

All the possible states of a physical system coexist in an n-dimensional space
- The number of dimensions may be infinite

**State vector** specifies the real state of the system

**State space** includes all the states of the system
State space

- Each state of a physical system is a spatiotemporal configuration of **fields**
- In each state, each field appears as a distribution of real and/or virtual **particles**
- In each state, each elementary particle has some momentum and energy
- The fields are **quantized**
  - Quantization generates uncertainty
  - The **quantum of action** $\hbar$ (about $6 \cdot 10^{-34}$ joule-second) is a tiny fuzzball of uncertainty in moment-energy-spacetime

\[
\Delta p \text{ or } \Delta E \quad \Delta E \Delta t \sim \hbar \\
\Delta x \text{ or } \Delta t \quad \Delta p \Delta x \sim \hbar
\]
A system can be in several states at once

- Generally, the system is in a superposition or mixed state of the possible observational values for an observable Q
- Each dimension of the state space is a pure state of Q
- Measurement nudges a mixed state to a pure state
Quantum worlds

As time passes, a quantum world focuses stepwise on ever more fully defined states.

Old world: time $t_1$

New world: $t_2 > t_1$

Interaction

Decoherence

Superposition of states
For each state, old probability $< 1$

Measured state
For this state, new probability $= 1$
Decoherence

- When a mixed state evolves to a pure state, a symmetry of possible states is broken
  - Actualization of one state breaks the symmetry
- Systems in mixed states decohere spontaneously during interaction with their environment
  - The interaction couples the system and its environment
- Coherent systems usually decohere very quickly
  - A system can decohere by coupling with a single quantum
Nonlocal correlations

- Multiparticle mixed states can be
  - Spatiotemporally extended
  - Distributed or scattered

- Nonlocal mixed states decohere
  - Simultaneously
  - To correlated pure states

  Even if detector choices are made after creation

Detector A measures spin up

Event creates correlated spin pair

Detector B measures spin down
Quasi-classical worlds

- In the series of worlds leading up to the actual world, each new world is consistent with its predecessors.
- Each new world has a history of symmetry breaking that leads back consistently to the primal moment.
  - The consistent history approach based on decoherence is the clearest interpretation to date of quantum theory.
  - For objects of mass > 1 fg decoherence times are < 1 as
    - Macroscopic worlds appear overwhelmingly classical.
  - Quantum superpositions studied so far are mostly
    - very small or
    - very cold or
    - very fragile.
Symmetries of a world relative to its superposed states break in **time**

- Superpositions decohere to pure states in time
- Moments of time are realized by approximately simultaneous devirtualization of fuzzy quanta

**Diagram:***

- Moment of time
  - Simultaneity is fuzzy
- Realization of quanta
  - Quanta vary in duration
Quantum computation

- In a classical computer’s n-bit register,
  - The n bits are each stored as distinct states 0 or 1
  - A single string of n bits can be stored at one time
  - Calculations for different strings run separately

- In a quantum computer’s n-bit register,
  - Qubits are stored as superpositions of 0 and 1
  - All possible $2^n$ strings of n bits are stored at once
  - Calculations for all the strings can run superposed – so long as the computation does not decohere
Physical computation

- Computation is a physical process
  - Information processing is **thermodynamic**
    - Information is negentropy
    - Losing information raises entropy
    - Reversible computation conserves entropy
    - Reversible computation conserves superpositions

- Commercial computers are physical machines
  - Their operation is more or less **deterministic**
    - They are made to perform classical computation
    - Only their components use quantum effects
    - Their computations are often irreversible
    - They create entropy like heat engines
Biological computation

- Biological processes may use quantum effects
  - Biological processes occur at molecular scales
  - At molecular scales quantum effects can dominate
- Neuronets can do fuzzy computing
  - ANNs can solve combinatorial problems by trial and error approximation
  - ANNs learn by thermodynamic relaxation
  - This is a classical stochastic process
  - In the brain, this is an extremely delicate analog process
    ➔ Thinking may involve quantum effects
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- Quantum theory
- Consciousness
- Open questions
- Conclusion
Worlds of consciousness

- Worlds
  - Embody the categorial structure of consciousness
  - Reflect the synthetic unity of consciousness

- Consciousness
  - Begins in sensory immediacy
  - Grows in an epistemo-ontic dialectic
  - Culminates in absolute knowledge

- Kant
- Hegel
Consciousness as process

- Human consciousness forms a VR in the brain
- The VR is identified with the actual world
  - The VR is adjusted in an ongoing evolutionary process to optimize its consistency with new sensory input

Input from the actual world G

G is reflected as VR in consciousness

Mind

The gap
Other minds

- Each consciousness inhabits a different world
- The private worlds of different minds overlap
- Their intersection forms a shared public world
  - A public world of information can grow independently of the minds that help define it
Self-consciousness is a self-referential loop

Consciousness forms a VR of its (former) self

Like universal sets in set theory, for consistency, the inner self must be a former conscious state.
Self-knowledge is a self-referential loop that forms a series of inner models of its former states

- Knowledge of a series of former states that form a meaningful evolution can be self-corroborating

Aus dem Kelche dieses Geisterreiches schäumt ihm seine Unendlichkeit

Schiller

The chalice of this realm of spirits foams forth to God, His own infinitude

Schiller
I am conscious

- I create an evolving VR that helps me survive in a natural world
  
  *Therefore*

- I am conscious

*Cogito Ergo Sum* Descartes

Our world

My world

Your world

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Consciousness implies an "I"
- The "I" is the 0 and V of the phenomenal world

"I" become an object as me
- I see you as object – You see me as object

"I" try to see me as myself
- I see an inner representation as myself
- I can intend the representation to be perfect
  - But it cannot be perfect

My self image is an imperfect reflection
Image quality is reduced in reflection
The conscious brain seems radically different from the inside and from the outside:

- From **inside**, it seems like a phenomenal world of qualia
- From **outside**, it seems like a wet lump of cells sustaining an intricate electrochemical dance with decahertz rhythms

The complementarity is *amazing* but not *absurd*.
Quantum consciousness

- Conscious states evolve in time like physical states
  - As time passes, superposed possible future states cohere or condense into unique actual present states
  - Possible states remain balanced in symmetry until the environment triggers realization of a unique state
  - States cohere at intrinsically fuzzy moments of time
    - Not past (states already fixed)
    - Or future (states still only possible)
    - But now (in the specious present)
  ➤ Is thinking quantum computation?

- Consciousness is unified
  - Like a Bose–Einstein (BE) condensate
    - Example: photons in a laser beam
Is consciousness photonic?

- Human consciousness is closely correlated with electrical activity in the brain
  - The cerebral electromagnetic (EM) field generates macroscopic waves over a range of frequencies
  - Synchronized neural firings produce coherent EM fields over regions ~1 cm with frequencies ~40 Hz
    - **Hypothesis:** these synchronized firings generate neural binding and unified percepts in consciousness - Singer
    - **Hypothesis:** neurons bound in groups support the functional architecture of consciousness - Edelman
    - **Hypothesis:** photons with frequency ~40 Hz form BE states that in the environment of the living brain have decoherence times ~100 ms (duration of the specious present) and are the quantum correlates of consciousness - Ross
Introduction

Formal logic

Computation

Set theory

Possible worlds

Quantum theory

Consciousness

Open questions

Conclusion
Brain states

- The brain is a VR generator
- Is the brain a quantum computer?
- Do its coherent 40 Hz EM fields evolve into superposed BE states?
- Are these the quantum correlates of consciousness?
Consciousness in context

- Our inner representation of the natural world is inseparable from that world itself
- We unite our representations in a shared public world
  - We must make regular updates of our inner worlds
  - We must accept public epistemological correction
- Private phenomenology is enslaved to public ontology
  - Biological evolution enslaves our minds to *nature*
  - The evolution of knowledge emerges from biology

The mind is a tool for survival
Intentional entanglement

- The identity of inner and outer worlds is **intentional**
  - Intentional identification is unconscious projection
  - The intentional medium is taken as transparent
  - Any structure imposed by the medium is taken as real
- Its quantum correlate may be **entanglement**
  - Inner states may be entangled with the natural world
  - Entangled states involve nonlocal correlations
A new scientific hypothesis must be experimentally testable – Popper
- It must make definite predictions
- The predictions must be falsifiable

A new paradigm must support a fertile research program – Kuhn
- It must support a family of scientific hypotheses
- It must motivate a program of detailed experiments
- The experimental results should be interesting and illuminating even if they overthrow the hypotheses

A quantum theory of consciousness
- Looks promising

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Experimental suggestions

- The miphic view of consciousness suggests that a quantum theory may be fruitful

- Experiments needed to test it:
  - Detailed brain-scan studies of phase locking and coherence in cerebral decahertz EM fields
  - Neurophysiological studies of how the cerebral interneural environment can support BE states
  - New techniques for in vivo measurement of decoherence times of interneural BE states
  - Statistical studies of correlations of localized BE states with subjective reports of conscious states
  - Measurements of perturbation thresholds for coherent interneural EM fields from extracerebral events
Can machines be conscious?

- If consciousness arises in BE states in EM fields,
  - Artificial consciousness (AC) should be possible
    - **Prediction:** AC will appear soon after quantum computation becomes a mature technology

- Present-day computers are classical
  - Their circuitry exploits quantum effects in semiconductors but their logical architecture is classical
    - **Prediction:** AC machines will exploit quantum effects in their logical architecture

- How will we know we have an AC?
  - Maybe a *zombie* can pass the Turing test!
    - **Prediction:** We will never build classical machines with the full range of human abilities
Consciousness in nature

- Which DNA based organisms enjoy consciousness?
Consciousness in the universe

- Is Gaia conscious?
- If so, where?
- And how?

- Are we part of a global self?
- Are we alone?
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To launch a science of consciousness we need a 3-stage booster

- **Mathematics of consciousness**
  The universe of sets gives a model

- **Informatics of consciousness**
  Information states evolve over time
  Virtual worlds surround the subject

- **Physics of consciousness**
  Quantum states grow and decohere
The science of consciousness today is like the science of electromagnetism at the time of Faraday

– Vilayanur Ramachandran

It’s possible that in the next hundred years something really surprising will happen that will make us look at the whole mind-brain problem in a new way. More likely, we’ll have a bunch of theories but still no consensus

– David Chalmers

In a hundred years, we’ll know the causal mechanisms that produce consciousness

– John Searle